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A REVIEW OF INTELLIGENT CNC CONTROLLER DEVELOPMENT BASED ON STEP-NC

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Abstract:

In the contemporary Computer Numeric Controlled (CNC) machine tools of Computer Aided Manufacturing (CAM) and CNC process conducted by a number of inter-related operations and parameters using G Codes and M codes set as RS274 or ISO 6983 standard. However, this programming language does not explicitly relate to each other to have control of arbitrary locations other than the motion of the block-by-block. STEP-NC is the extension to STEP, Standard for Exchange Product model data. This determines the neutral data format for digital information from a product. STEP-NC standard is on how information about CNC machining can be added to parts represented in the STEP product model data. In this paper is to review and explore the making of interoperable CNC manufacturing is then provided relating milling, turning, turn-mill through the development of information models for products, processes and new machining system controller developed base on new standard ISO 14649 standard and ISO 10303, which related to data modeling for CNC features, process planning, and machine tool. It is expected that this paper will meet a step towards the requirements for global interoperable manufacturing for real-life machining system.

Keywords: CNC; STEP; STEP-NC; STEP-NC CONTROLLER; INTEROPERABLE
camera ready.

1. Introduction

1.1 BACKGROUND

CNC manufacturing has evolved, with the use of computer and communication technologies in the manufacturing industries, the methods mentioned are towards intelligent control in CNC system to implement concurrent engineering. However, Over 50 years CNC has gone in manufacturing industries, the way of their programming the used of low level G-Code language are unchanged for the most of CNC machine. The G-code language was designed in the decade when paper tape was used for moving data between computers and CNC systems. Parallel to the technology change and market demand more than 70% of manufacturing businesses in the UK and the US rely on CNC machines as a part of their production capacity [1]. Widespread CAx chain (CAD/CAPP/CAE/ CAM) systems will reduce human interaction and the result, should be increased production quantity, reduced costs and quality of product.

1.2 ISO 6983

Since the CNC was introduced in the industrial sector has developed in the year 50s, CNC machines have been widely used in the manufacturing industry around the world because of its efficiency in processing, accuracy of the machines and facilities in operation. So far, most of CNC machines using G code M code, also known as ISO 6983 or RS274D. G and M codes is current programming language used in CNC machine. These codes are usually generated by the CAM tools and the information obtained from the CAD system. However, there are several problems [2] in the implementation of ISO 6983. Meanwhile, this problem occurred on CNC machines more magnified because of the role is required to play CNC machines in the manufacturing world. ISO 6983 is a low-level language mainly specifying the cutter motion position and feed rate. As shown in fig.1 the current cnc system of Cax chain more uni-directional. Each workstation making off-line software tools and generate the machine code for various post-processor generated by CAM which specified by manufacturer. CNCs of different vendors implement different versions of G-code which lacks any portability and leads to proprietary CAD–CAM–CNCchains[3-4]. Each CAM tools generate a different G-Code for CNC machine based on particular brand.

Any modification on shop floor not relies on CAM software and this make CNC system not intelligent or interoperability. There is no feedback to the CNC system after product has been finished. These capabilities of current technology have made the programming task increasingly more difficult and needs more effort on development of open controller.

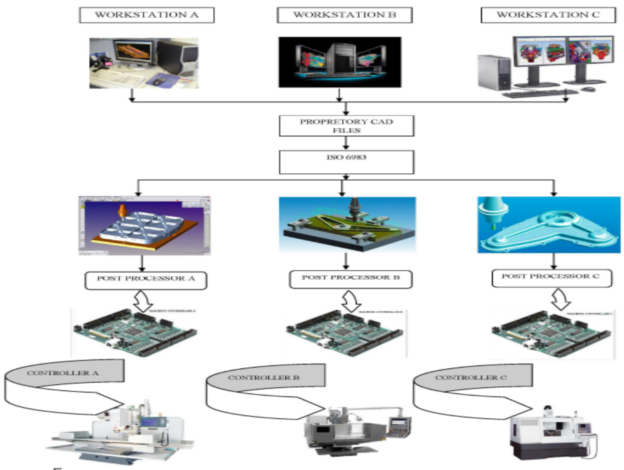

FIGURE 1: Current CNC technology chain

1.3 STEP AND STEP-NC

Now CNC multi-workstation configuration process has been changed to support the manufacturing industry, particularly in automotive manufacturing from low-volume to high-volume of volatile production components. This configuration provides a more flexible production of larger quantities involving more complex geometries, from the smallest to biggest a part, from the various combinations of materials and it is difficult to achieve through current standard. In future the manufacturing should more flexible and intelligent and with the concept found expression in DA-BA-SA (Design-Anywhere, Build-Anywhere, Support-Anywhere), which has become the catch phrase of e-Manufacturing [5]. Step-Nc as a new language has solution to replace the G and M codes that are used since 1950s in CNC. To overcome this problem from variety of standards, two different ISO subcommittees was developed a new standards known as ISO 10303(STEP) and ISO 14649(STEP-NC). ISO TC 184/SC4 subcommittees termed the Application Interpreted Model (AIM) are developing STEP-238 and ISO TC 184/SC1 subcommittees termed the Application

Reference Model (ARM) or ISO14649. These two models represent the data model information to program intelligent CNC controllers, but the AIM is fully STEP compliant, whereas the ARM contains the information required to program a CNC machine. The ARM is to be used in an environment in which CAM systems have exact information from the shop-floor, whereas AIM is more suitable for a complete design and manufacturing integration [6]. Both standards an international development aimed at achieving fully interoperability and bi-directional communication between Cax chain and shop floor [7].

2. REVIEW RELATED RESEARCH

Research teams working in the area of STEP-NC covered in this review include the UK, Germany, USA, New Zealand and China. . In figure 2 shows the research done in several countries.

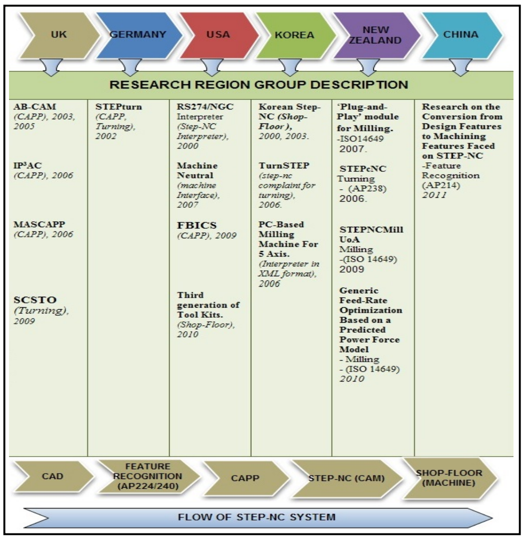

Figure 2: Research done in Different Country

2.1 Research in UK

Several numbers of research projects related to Step/Step-NC was conducted in UK. A project based on agent called AB was developed for STEP-NC compliant process-planning system [8-9]. Manufacturing Feature Agents (MFAs) as a STEP-NC manufacturing features for this system. MFA have two features, simple features are defined as autonomous MFAs, whereas combined features are defined as cooperating MFAs. Both types of MFAs can require corresponding manufacturing feature information from the Component Model and Manufacturing Resources Model including cutting tool information. The process planning tasks that are carried out include resource selection, operation selection, and machining parameter determination.

Nassehi et al. from the same research group analyzed each part of the STEP-NC standard for a potential application in an adaptive manufacturing system [Nassehi et al., 2006a] and as a result it capable to handle standard resource information storage. In Step-NC data are categories into three main group, product geometry model/manufacturing features definitions as in Parts 10(general) [10] and 11(milling) [11], interoperable manufacturing process models, and manufacturing resources models as in Part 111 [12] and 121 [7] and MASCAPP was developed based on this data model. Further research, Nassehi was developed a IP^3AC using Java programming language and presented a prototype namely process planning system (PPS) with two-strategy for part program generation; 1) general work plan generation; and 2) specific work plan generation. The turning operation system called SCSTO based on step-nc was developed to generate a Part 21 file based on machining features and validate through case study with prismatic part to support the interactive generation of process plans utilising feature extraction [13].

2.2 Research in Germany

The two German institutes, Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW) in Stuttgart and the Laboratory for Machine Tools and Production Engineering (WZL, RWTH) in Aachen play a role for European STEP-NC project. The research focus on the development and implementation of STEP-compliant

CAPP/CAM systems and NC controllers. Siemens as a vendor strongly support and backbone of the research project. STEPturn was developed at ISW as a prototype to adopt STEP and STEP-NC standards for turning operation. STEPturn is a CAPP system bridging CAD and CAM. Figure shows the concept of the STEPturn system. This system first reads geometrical data from a STEP AP-203 Part 21 file, and then performs process planning tasks such as feature recognition and Working step sequencing in order to generate a STEP-NC physical file [14]. However, this system cannot be used on other controller only fixed on Siemen 840 Controller.

The STEP-compliant CAM and NC controllers were developed at WZL, RWTH at Aachen University . This system based on the Siemens 840D controllers and it was the first industrial prototype of a STEP-compliant NC controller. In order to interface between human and machine, a graphical user interface (GUI) has been developed, using Shop Mill (a shop-floor-oriented NC programming tool) and Sinumerik 840D HMI (**H**uman **M**achine **I**nterface). This interface can parse STEP-NC program files [15-16].

2.3 Research in USA

In US Most of the active research work in STEP-NC was conducted by **N**ational **I**nstitute of **S**tandards and **T**echnology (NIST) and STEP Tools Inc. RS274/NGC Interpreter was developed to read STEP-NC ISO14649 Part 21 (physical file) schemas based on Part 10 and Part 11. This interpreter is a software system and written in the C++ programming language. Started in the late 1990s and continuing in 2000s, the EMC controller incorporate either an NC-program interpreter for programs written in the RS274 language or the ISO 14649 interpreter for programs contained in ISO 14649 STEP Part 21 files [17] . To interface between both program interpreter and lower level controllers for I/O and trajectory control in EMC the command prompt are used.

Boeing, as a giant of the aerospace industry and the collaboration with NIST proved useful in exposing potential areas of non-portability of AP238 TCP programs. For the pilot project, using the STEP-NC prove that exchange data can be work with three engine manufacturers for Digital Pre-Assembly on the 777 and 767-400 Extended Range Programs, Boeing conducted a pilot program to use STEP-NC to program CNCs with higher-level cutter motion data. Being “machine neutral”, the cutter motion data can be used by machines of differing types and configurations. For the software solution, a Catia V5 section 3 (CL) file is converted to a STEP-NC AP-238 Part 21 file, which for the next step is to translate into a configuration-independent part program file containing a machine cutter axis. The descriptions can be of either (1) **B**asic **C**ontrol **L**anguage (BCL), (2) the Siemens 840D version of G-code, or (3) the Fanuc version of G-code.

Kramer (2009) has developed process planning namely, Feature-Based Inspection and Control System (FBICS-ALPS) and compared with other three standard, ISO10303 (AP238, AP224) and ISO14649. (FBICS) has been built at the U.S. National Institute of Standards and Technology (NIST) that uses STEP methods and standards. The study found that AP238 and AP240 are difficult to produce a process planning, it needs a complex programming. In improvements in FBICS needed to make it industrially useful [18].

Research project was developed by STEP Tools Inc. who are software developers since 1991committed to improving engineering with smart, open product model data (step tools). The projects involved ST-developer software for STEP, CIS/2, or IFC support into any application . While, STEP-NC Machine is one of the software for creating, viewing, and machining with STEP-NC manufacturing data and this is a “new” product with the latest version V14. It creates machining programs that can be shared between many organizations and reused on many different machines. Hardwick [19] was developed a Third-generation STEP systems which combine data from existing systems to make

new data. This system was successfully tested on milling application and to a limited extent on turning applications. This system are continuing from previous research, starting with first generation of step system which, Express model as an input and process it with programming software (java etc.) into physical file. While, second generation of systems enhanced the first by adding tools to view and validate the data defined by the first STEP application protocols. The data exchange standard of the protocol is defined for 3D CAD data. This two generation system are reading and writing exchange data base on AP203 and AP214.
Figure below shows the third generation system proposed to relise in manufacturing which this system receive from various CAX sources. This system has connection to shop floor using the Step AP-238 standard from data produced. The CAD data and including tool path and process data form CAM then will use to combine both STEP GD&T data through direct interface or legacy format. The generated data then used by shop floor applications including all process planning, manufacturing optimisation, machining simulation and manufacturing control that need access to integrated product process data. However, Third generation system still needs to improve and to make it relies, the collaboration with machine manufacturer are must.

2.4 Research in KOREA

In Korea, there are two groups responsible for conducting research in the field of step-nc the National Research Laboratory for STEP-NC Technology (NRL-SNT) at Pohang University of Science & Technology and the Engineering Research Center for Advanced Control and Instrumentation (ERC-ACI) at Seoul National University. Suh et al. proposed an architecture and developed a prototype namely PosSFP [22], [20-21],. The research based on ISO14649 and suggests the work function framework into five modules, called (1) Shop Floor Programming System (PosSFP), (2) Tool-path Generator (PosTPG), (3) Tool-path Viewer (PosTPV) , (4) Man-Machine-Interface (PosMMI) and (5) CNC kernel (PosCNC). The study was carried out in phases, start with proposed a big framework up to of the prototype implementation. The controller is capable of performing a machining process based on an ISO 14649 data model [21].

A system called TurnSTEP was developed a prototype for step-compliant turning process, which is consists of three subsystems: (1) Code Generation System (CGS), (2) **C**ode **E**diting **S**ystem (CES) and (3) **A**utonomous **C**ontrol **S**ystem (ACS). This prototype has a potential to implement in future to realise in industries [23]. Lee et al. was developed interpreter PC-Based in XML format to generate Step-NC file part 21and this interpreter can be edited through Step-NC editor. Step-NC controller developed for milling machine can be generating a tool path for machining process automatically. All programming was developed using visual C++ [24].

The research group at School of Mechanical and Aerospace Engineering, Seoul National University concentrates on developing an XML-enabled STEP-NC data model for milling [Lee & Bang, 2003a, 2003b]. Lee *et al.* was developed a design for extensions of the interface to include other technologies [25]. While, Lee et al. also research for rebuilding XML files to reflect changes made to the user-specific data [26], and searching for, extracting and storing the tool-path generated in XML format. Research carry out in Korea was used ISO 14649 standard for developing Step-NC project, which aims for intelligent product data processing such as feature recognition, collision-free tool-path generation, automatic tool selection, and automatic process parameter selection, machining status and feedback control.

2.5 Research in New Zealand

Nearly all of the research work carried out at the **I**ntelligent and **I**nteroperable **M**anufacturing **S**ystems (IIMS) research group in the Manufacturing Systems Laboratory of the University of Auckland, aims to achieve a

STEP-compliant CAx and CNC environment. Development of STEP-NC with a goal to provide a data model for a new variety of intelligent CNC controllers.

Wang *et al.* proposed an adaptable CNC system based on STEP-NC and function blocks [4]. The system acts like a 'front-end' for current CNC controllers, giving this machine tool a 'Plug-and-Play' feature. This controller accepts STEP-NC data and translates it into the type of G-code that a specific controller can understand. The use of function block and Step-NC is a key for achieving intelligent, interoperable and adaptive CNC machining and it gives robustness and modularity to the system. Xu [3] was demonstrated STEP-compliant NC Converter called STEPcNC, where the STEP-NC file is converted into 6K programs and the data transfer to through the retrofitted lathe. This system can be write a 6K language and write a report file as a feedback.

Minhat [27] was developed a prototype called STEPNCMillUoA to realize Step-NC controller that combines Step-NC data model and the function block (IEC 61499). The prototype has been proved by simulation and actual machining. The architecture of the system consists of four main modules: (1) STEP-NC data, (2) STEP-NC to FB translator, (3) prototype of embedded CNC-FB, and (4) STEP-NC controller. The STEP-NC controller making use of the IEC 61499-based MVC framework takes maximum advantage of its highly visual nature. In order to optimize feed-rate Ridwan *et al.* was proposed system consists of three tasks: (1) Optimization task, (2) Process control task, and (3) Knowledge Based Evaluation (KBE) task [28]. Which, this system will calculate and estimate the cutting force based on nominal powers given and other production information.

2.5 Research in China

A new methodology was proposed for converting design features of a feature-based design part model into machining features [29]. Algorithms is used for modeling data from CAD file, which can be created in Solid Works or imported from any CAD software in format of Step file (.stp). The results show that, this method possible to implement for integration with other CAD/CAPP/CAM.

3. Conclusions And Future Work

The Changes in the economic climate has grown considerably to force manufacturers to move in line with technological developments in the field of manufacturing engineering to develop the latest technology like the design, manufacture and assembly worldwide. As a result, AIM and ARM (ISO 10303 and ISO 14649) has been developed to realize the development of CNC technology in the manufacturing company. Current implementations only in academic level and yet to gain widespread support and cooperation of industry sectors. It is long way to go if it is not getting the support and cooperation with manufacturers. The development of Step-NC system for turning and milling done by researcher separately. No significant work has been done on combining the two parts for turn/mill components [30]. The major challenge to researchers for the development of this intelligent controller is the barrier of the software / hardware vendors are seeing the lack of standards for manufacturers to take the opportunity to maintain their market advantage through the lock-in. Interoperable manufacturing will become a reality only if the consumer pressure forced the vendors to integrate their products in open-source. Table 1 shows a summary of the review , which including the problem or limitation faced by researcher according to several country. The authors believe that STEP-NC is one enablers in future will be reached. In future, feedback element and online control for the CNC system should be covered, in order to realised intelligent controller for CNC.

Researcher	Year	title	Technology	Problem/limitation
			UK	
Allen et al.	2003 2005	AB-CAM	CAPP	- Still unsolved problem in knowledge-based planning system.
				- NC programmer efficiently
				- Rapidly customised
				- automatic manufacturing data update
Nassehi,	2006	IP³AC	CAPP	- Manually translating each EXPRESS definition into a JAVA class definition
Nassehi,	2006	MASCAPP	CAPP	- Only for Prismatic components (closed pocket and round hole)
				exported STEP-NC files are then interpreted and 'simulated on a SIEMENS controller with SHOPMILLe OPEN 6.03 software.
Yusri	2009	SCSTO	Turning	- Only generate text file (part 21 for turning). Involved turning and milling features in case study.
			GERMANY	
Storr *et al*,	2002	STEPturn	CAPP,Turning	- Tested for single working step only
			(AP203)	-Tested only for Srecific machine (siemen
			USA	
Kramer, et al.	2000	RS274/NGC Interpreter	ISO14649 Interpreter	- Lower level language still used for integrate with machine controller
				- Not user friendly, command prompt are used for interfacing.
Boeing and NIST	2007	"machine neutral"	ISO10303, AP238	-Used limited process parameters for
			Controller	feeds and speeds in the TCP program
				- Just focus on Portability rather than autonomous
Kramer	2009	FBICS	CAPP	- Suggest eight(8) criteria to be improve in
M. Hardwick,	2010	Third generation of Tool Kits.	Milling, AP238.	-Poor Result
			KOREA	
Suh *et al*	2002, 2003	PosSFP	Milling	- Feature recognition cannot be recognise automatically.
		Korean Step-NC	(ISO 14649 or	
Lee *et al*	2006	PC-Based Milling Machine Interpreter	Interpreter for Milling 5 Axis in	- No standard model XML format
			(ISO 14649)	- System cannot generate automatically for additional information.
Suh *et al*	2006	TurnSTEP	Step-Compliant for Turning	-Operator should define material information and some features manually.
			(ISO 14649)	-Not fully autonomous and intelligent
			NEW ZEALAND	
Wang *et al*	2007	An adaptable CNC system based on STEP-NC and function blocks	'Plug-and-Play' module for Milling.	- Still used ISO 6983 for end controller
			-Shop Floor	- Step-NC only act as converter for the current controller.
			(ISO 14649)	
Xu *et al*	2006	Realization of STEP-NC enabled machining	Turning -AP238	- Different machine controller needs to developed a different interpreter of Step-NC (different NC kernel).
		(STEPcNC)		-Used low level language.
Minhat, M. *et al*	2009	STEPNCMillUoA: a CNC system based on STEP-	Milling ISO 14649 -	- Offline process
				- Only 3D wireframe simulation
				- No Feedback data to controller.
Ridwan *et al*	2010	Generic Feed-Rate Optimization Based on a Predicted Power	Milling ISO 14649 -	- No feedback data to Step-NC Controller for error correction.
			CHINA	
Hua-bing ,Ouyang and Bin, Shen	2011	Research on the Conversion from Design Features to Machining Features Faced on STEP-NC	Feature Recognition (AP214)	-The example demonstrates designed features covered only: rectangular body, irregular pocket, through holes, reblind holes, irregular pocket, rectangular slot and blind hole.

Table 1: Summary of the review

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